# Lecture -8 (Measuring CPU Performance)

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→ Execution of instructions
→ Existing architectures
→ addressing modes
→ instruction formats

Program → no. of instructions

CPU 1     CPU 2

Which CPU is better?

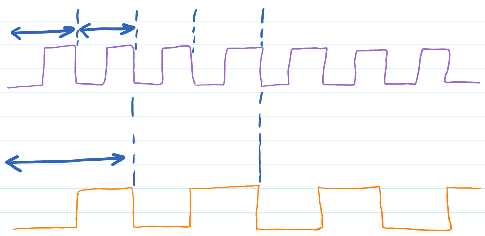
## Clock Rate / Frequency :–

Most processors execute instructions in a synchronous manner using a clock that runs at a constant **clock rate** or **frequency f.**

→ The execution of the an instruction/task is performed during clock period.

Clock Cycle time (C) is reciprocal of clock rate f:

$$C = 1/f$$



$F = 1GHz = 10^9 Hz$

$C = \frac{1}{f} = \frac{1}{10^9} sec = 1 nsec$

$F = 500 MHz$
$= 500 \times 10^6 Hz$

$C = \frac{1}{f} = \frac{1}{500 \times 10^6} sec = 2 nsec$

Clock cycle frequency depends on two factors

① Implementation Technology

→ size of transistors becoming smaller, clock speed faster.

② CPU organization

→ how to organize the CPU such that, the number of tasks performed can be maximized.

For a given machine,

(a) Instruction Count (IC)

Total number of instructions executed.

(b) Cycles per Instruction (CPI)

Average no. of cycles for one instruction.

(c) Clock Cycle Time (C) of the machine.

**Total execution time (XT) = IC × CPI × C**

Comparing the performance of two machines (A, B)

→ Measure the execution time of some program on both the machines (A and B)

$XT_A$ and $XT_B$

Performance can be defined as,

$$Perf_A = 1/XT_A$$

$$Perf_B = 1/XT_B$$

→ Speed up of A over B,

$$Speedup = Perf_A / Perf_B = \frac{XT_B}{XT_A}$$

Example 1:- Given, parameters of a program running,

No. of instructions = 50k

Average CPI = 2.7

CPU clock rate = 2.0 GHz

## Execution Time of the program?

CPU clock rate (f) = 2.0 GHz = $2 \times 10^9$ Hz

Clock cycle time, $C = \frac{1}{f}$

$= 0.5 \times 10^{-9}$ sec.

Execution time (XT) = IC × CPI × C

$= 60{,}000 \times 2.7 \times 0.5 \times 10^{-9}$

= ______ sec.

### Factors Affecting Performance

| | C (Clock Cycle Time) | CPI | IC |
|---|---|---|---|
| Harware Tech. | X | | |
| CPU organization | X | X | |
| ISA | | X | X |
| Compiler Technology | | X | X |
| Program. | | X | X |

So, it is difficult to change one parameter in complete isolation from others.

### Tradeoff :-

**RISC:-** ↑ # instructions
↓ CPI

**CISC:-** ↓ # instructions
↑ CPI

⇒ Overall, RISC architecture gives better performance.

(through experimentation).

## Instruction Types and CPI:-

Let program has 'n' types of instructions (eg. load, store, branch, etc.)

$IC_i$ = number of instructions of type i executed.

$CPI_i$ = cycles per instruction for type i.

$$\text{Total Inst}^n\text{ Count }(IC) = \sum_{i=1}^{n} IC_i$$

$$\text{Total CPU clock cycles }(C) = \sum_{i=1}^{n}(IC_i \times CPI_i)$$

$$CPI = \frac{C}{IC}$$

**Example:-** Let 4 types of instructions with CPI, 1,2,3,4, respectively. Instruction Counts are 20, 15, 5, 2, respectively. What is CPI?

| | Type 1 | Type 2 | Type 3 | Type 4 |
|---|---|---|---|---|
| $CPI_i$ | 1 | 2 | 3 | 4 |
| $IC_i$ | 20 | 15 | 5 | 2 |

$IC = 20 + 15 + 5 + 2 = 42$

Clock cycles $= 1\times 20 + 2\times 15 + 3\times 5 + 4\times 2$
$= 73$

$CPI = \frac{73}{42}$

$\boxed{CPI = 1.74}$

## Instruction Frequency and CPI:-

CPI can also be expressed in terms of frequencies of instruction types.

$F_i$ denotes the frequency of execution of inst$^n$ type i.

$$F_i = \frac{IC_i}{IC}$$

$$CPI = \sum_{i=1}^{n} (F_i \times CPI_i)$$

Example:-

| Type | Frequency | CPI |
|---|---|---|
| Load | 20% | 4 |
| Store | 8% | 3 |
| ALU | 60% | 1 |
| Branch | 12% | 2 |

Cycles per instruction CPI?

$$CPI = \sum_{i=1}^{n} F_i \times CPI_i$$

$$= 0.2 \times 4 + 0.08 \times 3 + 0.6 \times 1 + 0.12 \times 2$$

$$= 1.88$$

Bench Mark:- Standard metric used for comparison.

(a) MIPS (Million Instructions Per Second)

$$\frac{IC}{XT} \times 10^{-6}$$

(b) MFLOPS

Quiz Question:-

Machine A,

$IC = 50,000$

average $CPI = 2.7$

clock rate $= 2.0$ GHz

} same as example 1.

Machine B

Machine B,

IC = 40,000

average CPI = 3.0 (more complex instructions)

clock rate = 2.4 GHz (faster)

Speed Up ?

(in %age)